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Evaluation of the fetal state by automatic analysis of the heart rate

1. Deceleration areas and APGAR score

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Electronic monitoring of the fetal heart rate (FHR) for diagnosing fetal distress during labor has made great progress in the past ten years. We now know that fetal well-being is reflected by absence of heart rate deceleration, maintenance of beat-to-beat fluctuation, and normal baseline level.

1.1 Subjective classifications

Many authors [1, 2, 4, 16] have tried **to classify FHR patterns into different categories in attempts, to help in the detect on of early symptoms of fetal distress.** All known classifications have the same flaw: they are **subjective** and could be **interpreted differently.** On the other hand, the appearence of fetal heart rate (FHR) patterns also depends on the strip chart speed and the scale. Moreover the prognostic significance of these classifications appears to be a relatively weak one and fetal distress has been reported in cases of Dip I or early decelaration. **The physiopathologic meaning of these various types of classification is also questionable.** The information derived from such fetal heart rate recordings is qualitative and is difficult to correlate with quantitative clinical and biological findings.

1.2 Objective data

Since 1967, SUREAU [5, 7, 8, 9, 10, 11] has advocated **the usefulness of quantifying FHR recordings in order to obtain objective condensed and numerical data** concerning fetal heart rate. Since 1968, the Baudelocque research group has attempted to build a monitor capable of evaluating certain FHR parameters, notably deceleration areas and beat-to-beat fluctuations during labor.

Curriculum vitae

G. STURBOIS *(M. D.) was born in Binche (Belgium) in 1945. He went to medical school in Namur (1963 to 1964) and at the Université Catholique de Louvain where he received his degree in 1970. He was resident in obstetrics and gynecology, detached from the Université de Louvain (Chairman: Prof.* J. A. SCHOECKAERT*) to the Clinique St. Michel (Brussels) (Head: Dr.* R. MINGEOT*). Since October 1972, he has been foreign resident at the Clinique Universitaire Baudelocque — Paris (Chairman: Prof.* F. LEPAGE*) and has worked in the research unit (Head: Prof. Agr.* C. SUREAU*).*

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In this paper we present preliminary computation results of FHR deceleration areas made by a special purpose digital computer. These are correlated with the one minute APGAR score.

2. Patients and methods

The majority of our 97 patients were **high risk pregnancies,** due essentially to their special selection in our hospital and to the fact that we monitor high risk patients. Most of the women were given a psychoprophylactic preparation for delivery, obviating the use of analgesic drugs. We never administered atropine or equivalent drugs. Out of these 97 patients, there were 71, spontaneous vertex deliveries, 2 breach deliveries 12 were delivered with forceps (6 with acute fetal distress), and 12 by cesarian section (8 with acute fetal distress). We gave no anesthetic for spontaneous vertex deliveries. For breach and forceps deliveries we used pudendal block. For cesarian sections and for mid forceps deliveries we gave a general anesthetic. The results from 4 other cases were eliminated because of "noisy" tracings.

The trigger used to obtain the FHR curve was the **filtered R wave of the fetal electrocardiogram.** It was obtained by means of an electrode attached to the presented portion of the fetus. We used two different types of electrodes: suction electrode (CHAVINIE), spiral electrode with one (PAUL) or two (RÜTTGERS) spirals in stainless steel. The quality of the signal was the same for both types of electrodes; however, the spiral electrode produced clearer results during uterine contractions.

Intrauterine pressure was obtained with an intrauterine 16 gauge I. D. teflon catheter introduced transcervically and attached to a STATHAM strain gauge. These two fundamental signals were transmitted in three directions:

a) towards a **cardiotocograph Monitor 5** (ROCHE BIOELECTRONICS) which displayed a FHR curve with a scale in beats per minute and a pressure curve in mm of Hg,

b) towards a **tape recorder,**

c) towards the FHR **computer.**

The final results of the computation (FHR, intrauterine pressure, deceleration areas) were displayed on a **strip-chart,** at a speed of 2.5 centimeters per minute. All these data were also shown by **digital display.**

The **principle** of this special purpose computer has been described by SUREAU et al. in previous papers [9, 10, 11, 12, 13, 14]: By sampling every 20 milliseconds, the computer measured the difference between the value of the past interval (Period) and the value of the base line, both expressed in milliseconds. These values were added together from the beginning to the end of every deceleration. The total of these values multiplied by the length of time between each calculation (20 milliseconds) gave the value of the area delineated by the base-line and the FHR curve (linear to the period).

The two dimensions of this area (intervals in ordinate and time in abcissa) were expressed in seconds, therefore, the area unit was square second (s^2).

We obtained at every moment of the tracing, the summed area of the last monitored period. However, for research purposes, because we monitored patients during unequal periods of time (from 15 minutes to 6 hours) the area measurements of the complete tracings were averaged to a period of one hour for each patient (s^2/h).

By means of a threshold on the intra-uterine pressure curve (U. C.), we were able to obtain 3 different kinds of areas (Fig. 1).

1. **Total deceleration area (At)** computed from the beginning to the end of a deceleration.

2. **Residual deceleration area (Ar)** computed between contractions only.

3. **Simultaneous deceleration area (As)** computed as difference between total area and residual area and equivalent to the deceleration during uterine contractions.

These different types of areas were correlated with APGAR score. In order to evaluate the clinical state of newborns, one and five minute APGAR scores were determined always by the same obstetrician. Statistical computations were made by calculating correlation coefficients, regression lines, and chi-square tests.

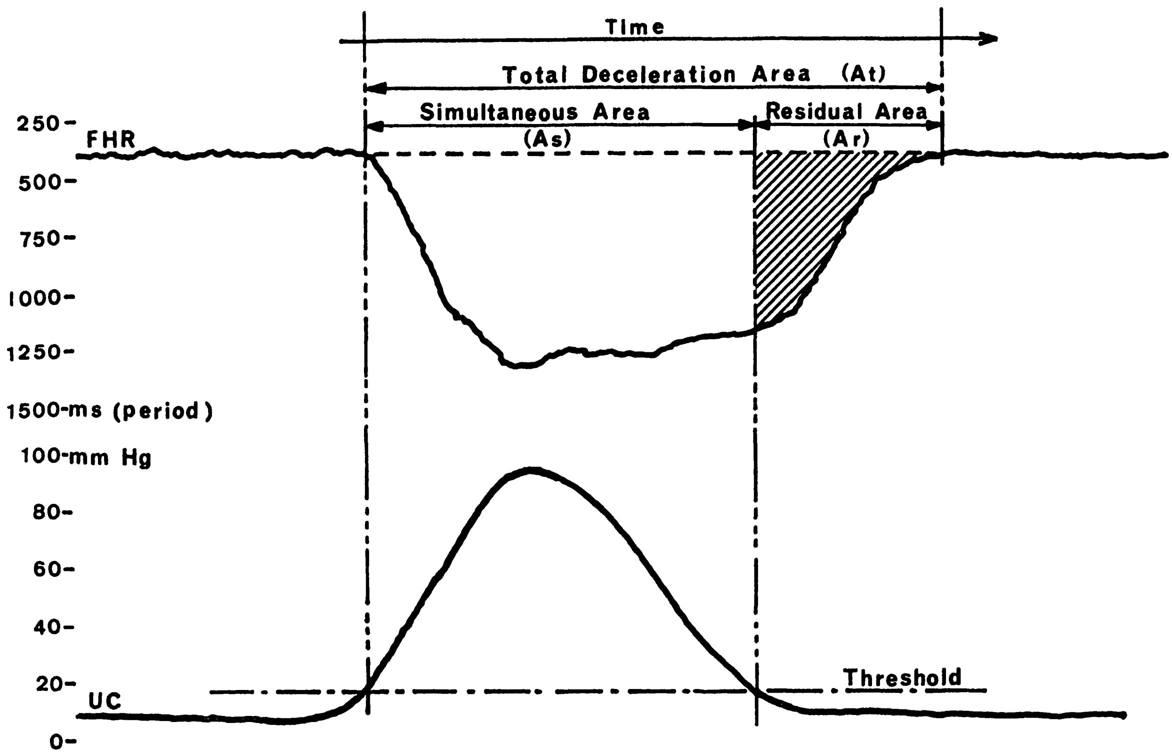


Fig. 1. The three different kinds of areas measured by the calculator.

3. Results

In our group of patients 72 newborns had a one minute APGAR score of 7 or more (74%). The number of newborns with a low five minute APGAR score was too small to make an evaluation. Figs. 2 to 4 show **the relationship between the 3 types of areas expressed in square seconds per hour (s^2/h) and one minute APGAR score.** All had **highly significant** correlation coefficients (Tab. I). We tried to determine for each type a limit value of area to predict efficiently low and high APGAR score, by calculating the 3 regression lines. From this, we evaluated on the abcissa the value of area corresponding to APGAR 7 on the ordinate.

Tab. I. Correlation coefficients of deceleration areas and one minute APGAR score.

Areas	Correlation coefficients
Simultaneous (As)	—0.67
Total (At)	—0.61
Residual (Ar)	—0.43

The limit values of area between the cases with high and low one minute APGAR score were respectively 105 square seconds per hour (s^2/h) for total deceleration area (At), 70 square seconds per hour (s^2/h) for simultaneous area (As) and 35 square seconds per hour (s^2/h) for residual area (Ar). Figs. 5 to 7 show the assessment of one minute APGAR score with different types of area. The correlations are highly significant for the 3 kinds of deceleration area ($p < 0.0001$). **The worse correlation coefficient was obtained with residual area.** In our group of patients when total area was smaller than 105 s^2/h, one minute APGAR score was 7 or higher in 88% of cases. When this area was 105 s^2/h or larger, one minute APGAR score was 6 or lower in 94% of cases.

4. Comments

Our purpose was to verify if computation of deceleration areas was a good parameter for assessing FHR monitoring. By measuring different types of deceleration areas, we wanted to know

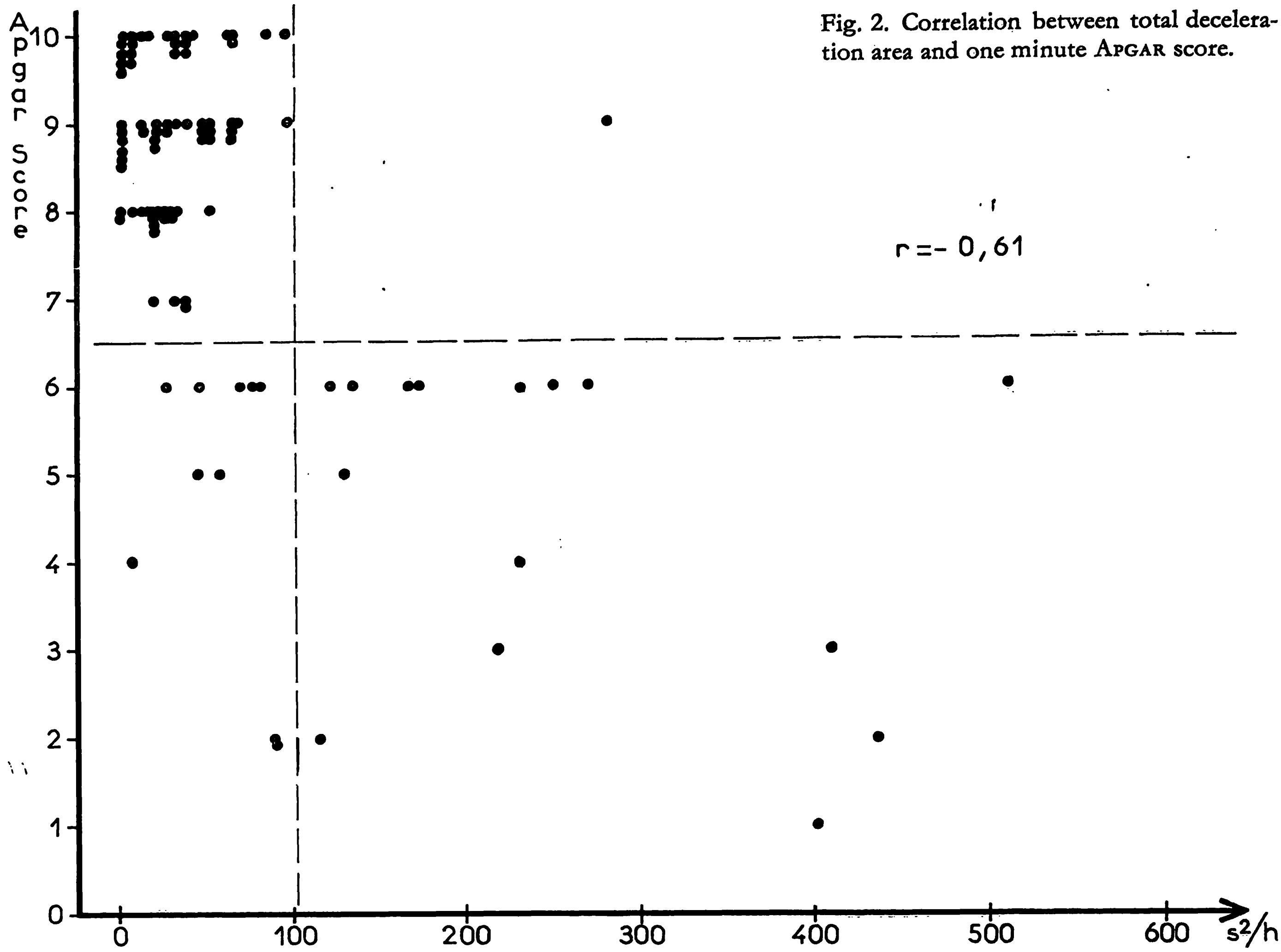


Fig. 2. Correlation between total deceleration area and one minute APGAR score.

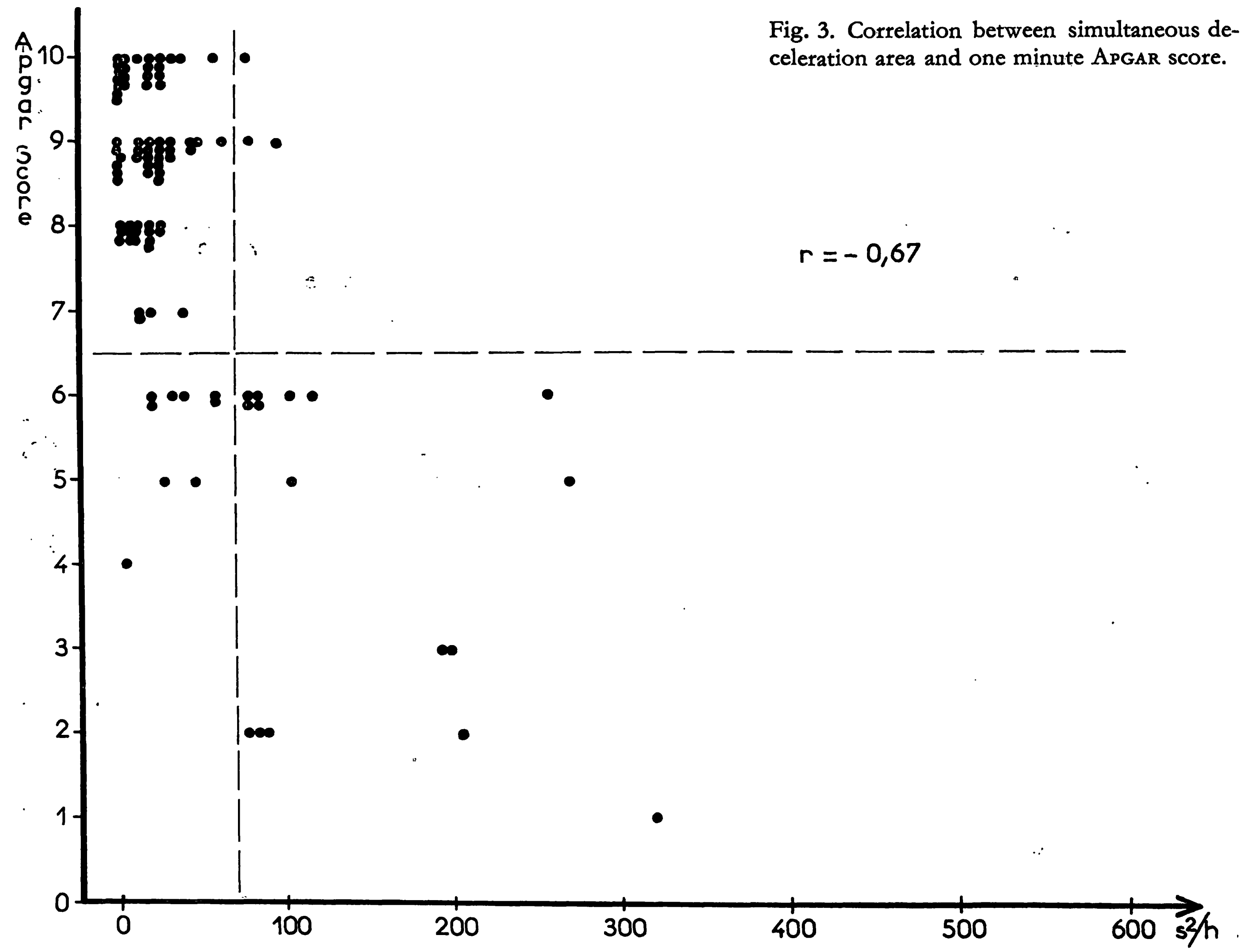


Fig. 3. Correlation between simultaneous deceleration area and one minute APGAR score.

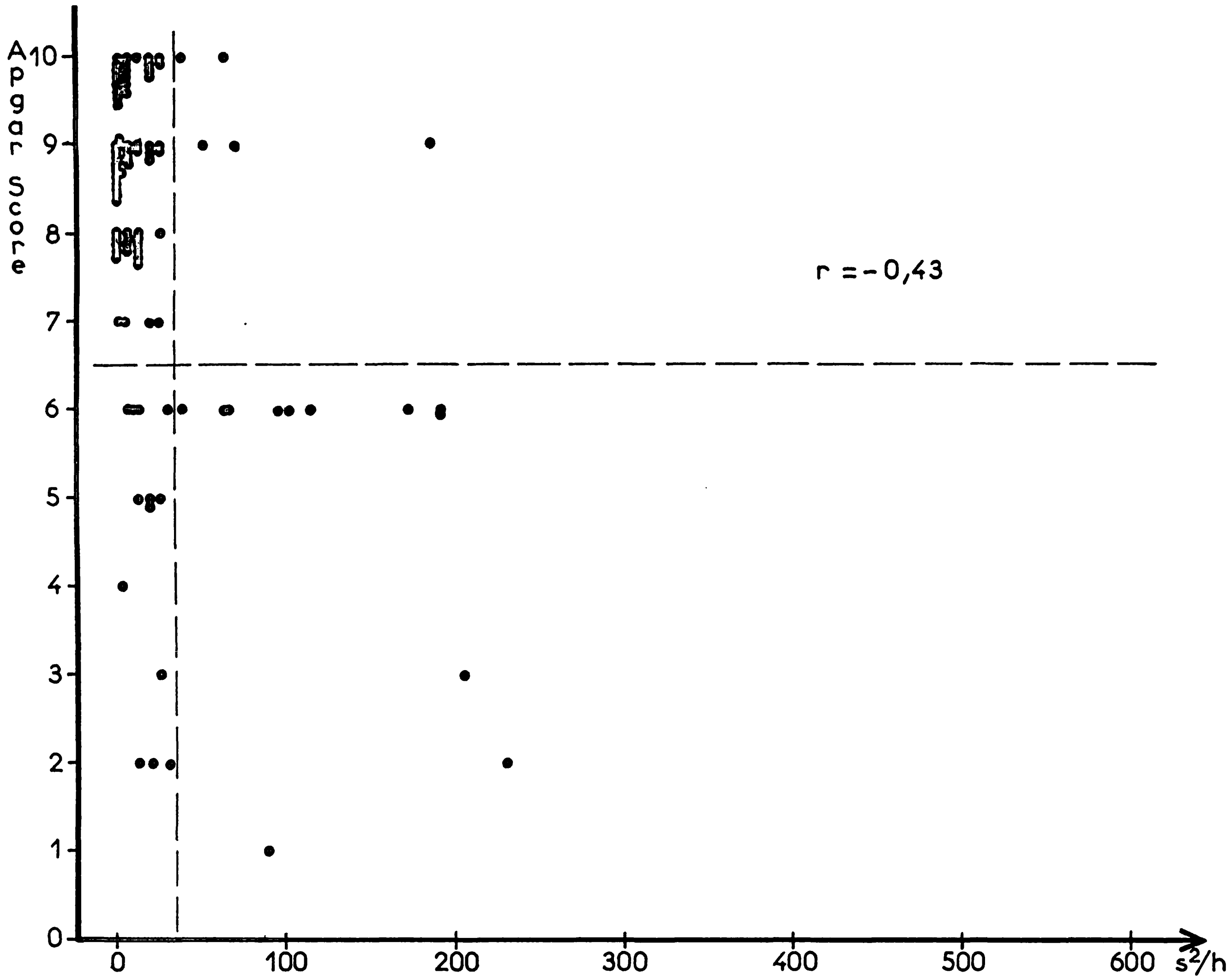
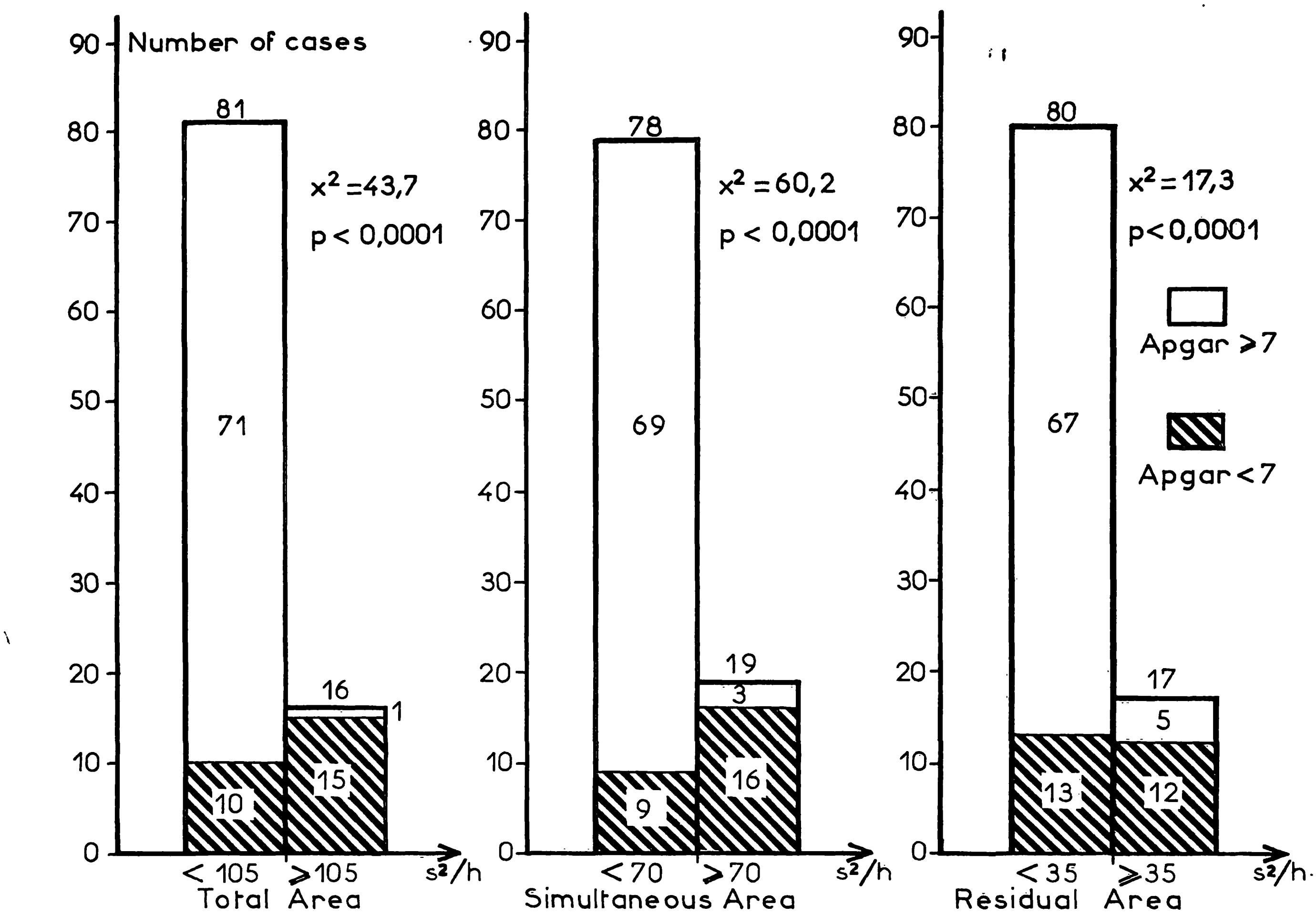


Fig. 4. Correlation between residual deceleration area and one minute APGAR score.

if **time relationship between uterine contractions and decelerations was an adequate measure for distinguish between ominous and innocuous decelerations** as suggested in clinical classifications [1, 2, 4, 16]. In our group of patients apparently the areas of deceleration alone was of greater interest in evaluating fetal state than the time relationship. Deceleration areas were measured previously by some authors, either manually [3, 6], or by means of computer [15]. These research techniques were not convenient for widespread clinical use. These authors studied **retrospectively** their tracings and calculated deceleration areas during **the last hour of labor** without considerating decelerations observed earlier in labor. **In our study, we computed deceleration areas "on line" from the beginning of the tracing to delivery,** and chose our unit of area independent of the length of monitoring by averaging deceleration areas during the whole period, (square seconds per hour), a computation apparently lacking accuracy: many small decelerations could be significantly different from that of a few large decelerations of the same area.

Our unit (s^2/h) depends directly on the measured phenomenon (interval between 2 R waves). We used, therefore, a scale expressed in interval between beats (which seems to us the primary phenomenon) instead of frequency scale. In another method, FHR may be expressed **in a frequency scale** (beats per minute) and **areas measured in missed beats;** this corresponds to the number of beats which would have occurred



Figs. 5 to 7. Limit values of area between newborns with high and low one minute APGAR scores for total, simultaneous and residual areas.

without deceleration. Perhaps this is a method of computation easier to understand. There is a mathematical relationship between these two measures. The respective usefulness of both types of calculations could be evaluated.

In our study, the 3 different kinds of area (At, As, Ar) correlated reasonably well (Tab. I) with the one minute APGAR score; however, the **best correlation coefficients were obtained by measuring total or simultaneous areas.** It is probably due to the fact that in our patients the most frequent type of deceleration was **variable pattern** where the residual area is very small when compared with total or simultaneous areas.

Because of our large proportion of high-risk patients, the limits established for this group should not be used in practice yet. The best limit to differentiate between the 2 groups of fetus must be determinated with a more representative sample of patients and correlated with other parameters such as fetal biochemistry. This will be presented in a further paper.

Summary

Electronic monitoring of fetal heart rate is a usefull parameter for detecting fetal distress. Many authors have tried **to classify FHR patterns into different categories.** Unfortunately, all these classifications are **subjective** and could be **interpreted differently** by everyone. Furthermore, information derived from such fetal heart rate patterns is **qualitative** and difficult to correlate with quantitative clinical and biochemical parameters. A parameter easy to

quantify is the **area of deceleration** delineated by FHR curve and baseline.
The Baudelocque research group built a special purpose **digital computer for measuring this area.** The principle of our computer was previously discribed by SUREAU et al.

Patients and method

The trigger used for FHR recording was the filtered R wave of the fetal electrocardiogram. An intrauterine pressure curve was obtained with an intrauterine teflon catheter introduced transcervically and attached to a STATHAM strain gauge. These 2 fundamental signals were transmitted:

a) towards a **cardiotocograph monitor 5** (ROCHE BIOELECTRONICS).

b) towards a **tape recorder.**

c) towards the **FHR computer.**

The results of computation were displayed on a **strip chart** and by **digital inscriptions.** By means of a threshold on intrauterine pressure curve, we obtained 3 kinds of areas

1. **total deceleration area (At).**
2. **residual deceleration area (Ar),**
3. **simultaneous deceleration areas (As) (Fig. 1).**

The unit of area was square second. Because we monitored our patients "on-line" during unequal periods, the areas were averaged to a period of one hour and the results expressed in square seconds per hour.
The results of computation were correlated with one minute APGAR scores of 97 newborns (71 spontaneous vertex deliveries, 2 breach deliveries, 12 forceps and 12 cesarian sections).

Results

We found highly significant correlation coefficients for each type of area (Tab. I). We determined for each area a limit value to predict low and high one minute APGAR scores, by calculating the respective regression lines. From these we evaluated on the abcissa the value of area corresponding to APGAR 7 on the ordinate (Figs. 2 to 4). The 3 limit values were respectively 105 square seconds per hour for total area (Fig. 5), 70 square seconds per hour for simultaneous area (Fig. 6) and 35 square seconds per hour for residual area (Fig. 7).
In our patients when total area was smaller than 105 square seconds per hour, one minute APGAR score was 7 or higher in 88% of cases. When this area was 105 square seconds or larger, the APGAR score was 6 or lower in 94% of cases.

Comments

By means of this computation, apparently **deceleration areas are a more reliable parameter of fetal distress** than the time relationship between deceleration and uterine contractions. We chose our unit depending on the interval between 2 R waves. In an other method, FHR may be expressed in frequency scale and areas measured in missed beats.
Because of our small number of patients, the limits established for this group should not be used in practice yet.
Correlation between biochemical state of the fetus or newborns and deceleration areas will be presented in a future paper.

Keywords: APGAR score, deceleration area, distress, fetus, heart rate, monitoring system, uterine contraction.

Zusammenfassung

Die Beurteilung des fetalen Zustandes mittels einer automatischen Herzanalyse.

1. Dezelerations-Fläche und APGAR Punkte

Die elektronische Überwachung der fetalen Herzfrequenz stellt einen sehr brauchbaren Parameter zur Erkennung des fetalen Zustandes dar. Bereits mehrere Autoren haben den Versuch unternommen, **Einteilungen für die Herzfrequenzkurven** zu schaffen. Doch leider sind diese Einteilungen **subjektiv** und **unterschiedlich auslegbar.** Zudem ist die Information aus solchen fetalen Herzfrequenzkurven eine **qualitative** und nicht leicht korrelierbar mit den klinischen und biochemischen Befunden, die quantitativ sind. Als einfacher Parameter zur Umformung in eine meßbare Größe bietet sich daher die **Dezelerationsfläche** an, die sich zwischen der Herzfrequenzkurve und der Nullinie ergibt.
Die Forschergruppe der geburtshilflichen Klinik Baudelocque hat ein **digitalanzeigendes Gerät entworfen, um diese Fläche zu berechnen.** Das Prinzip dieses Apparates wurde von SUREAU et al. in vorangegangenen Veröffentlichungen beschrieben.

Eigene Beobachtungen und Methode

Als Signal zur Erstellung der Herzfrequenzkurve dient die R-Zacke des EKGs des Feten. Die intrauterine Druckkurve erhält man mit Hilfe eines in die Fruchtwasserhöhle eingeführten Plastikkatheters, der an eine Druckdose nach STATHAM angeschlossen ist.

Diese beiden Ausgangssignale werden übertragen:

a) auf einen **Kardiotokograph-Monitor 5** (ROCHE BIOELECTRONICS),

b) auf einen **Magnetschreiber,**

c) auf ein **Rechengerät** zur Berechnung der Herzschlagfrequenz.

Die Rechenergebnisse werden auf einem **graphischen**

Schreiber und auf einem **Digitalschreiber** angegeben. Entsprechend Anfang und Ende der intrauterinen Druckkurve können wir drei Typen der Dezelerationsfläche erhalten:

1. **Gesamtfläche (At),**
2. **Residualfläche (Ar),**
3. **gleichzeitige Fläche (As)** (Fig. 1).

Unsere Flächeneinheit ist die Quadratsekunde. Da wir unsere Patientinnen unterschiedlich lange am angeschlossenen Gerät überwachten, haben wir den Stundendurchschnitt der gemessenen Flächen berechnet und die Ergebnisse in Quadratsekunde/Stunde angegeben. Wir haben bei 97 Neugeborenen die Korrelationen zwischen den Ergebnissen unseres Rechengerätes und dem Apgar-Score in der ersten Minute aufgestellt (71 Spontangeburten in Kopflage, 2 in Steißlage, 12 Zangen und 12 Kaiserschnitte).

Ergebnisse

Wir haben einen sehr signifikanten Korrelationskoeffizienten für jeden Flächentyp gefunden (Tab. I). Wir haben für jede Fläche einen Grenzwert aufgestellt, der uns erlaubte sowohl schlechte als auch gute Apgar-Scores in der ersten Minute durch die Berechnung der verschiedenen Regressionslinien vorauszusagen. Nach diesen Regressionslinien haben wir auf der Abszisse den Flächenwert berechnet, der dem Apgar-Wert 7 auf der Ordinate entsprach (Fig. 2 bis 4). Die drei entsprechenden Grenzwerte waren für die Gesamtfläche 105 Quadratsekunden pro Stunde (Fig. 5), für die gleichzeitige Fläche 70 (Fig. 6) und für die Residualfläche 35 Quadratsekunden pro Stunde (Fig. 7).

Bei 88% der Beobachtungen mit einer Gesamtfläche unter 105 Quadratsekunden pro Stunde lag der Apgar-Wert in der ersten Minute bei 7 oder darüber. Bei 94% der Patientinnen mit einer Fläche von 105 Quadratsekunden oder darüber lag der Apgar-Wert unter 7.

Bemerkungen

Nach dieser Methode erscheint es uns berechtigt, die **Dezelerationsflächen der fetalen Herzfrequenz als einen genaueren Parameter zur Beurteilung des Zustandes des Feten** anzusehen als die Korrelation der Zeit zwischen der Dezeleration und der Wehe. Wir definierten unsere Einheit nach dem Zeitabstand zweier R-Zacken.

Einer anderen Methode zur Folge könnte man die fetale Herzfrequenz nach einer Frequenzskala bestimmen und die Flächen nach fehlenden Schlägen messen.

Aufgrund unserer kleinen Anzahl von Patientinnen können die von uns aufgestellten Grenzwerte noch nicht in der Praxis angewendet werden.

Die Korrelationen zwischen den biochemischen Werten des Feten und des Neugeborenen mit den Dezelerationsflächen sollen der Inhalt einer späteren Mitteilung sein.

Schlüsselwörter: Apgar-Schema, Dezelerationsfläche, Fet, Herzfrequenz, Überwachung, Wehe.

Résumé

Evaluation de l'état foetal par l'analyse automatique du rythme cardiaque.

1. Surface de la décélération et score d'Apgar

La surveillance électronique du rythme cardiaque foetal est un paramètre très utile pour depister la souffrance foetale. Plusieurs auteurs ont essayé **de classifier les courbes de rythme cardiaque foetale** en différentes catégories. Malheureusement, ces classifications sont **subjectives** et **différemment interprétables** par chacun. Bien plus, l'information obtenue à partier de pareilles courbes de rythme cardiaque foetal est **qualitative** et difficile à corréler avec les données cliniques et biochimiques qui sont quantitatives. Un paramètre facile à quantifier est la **surface de ralentissement** comprise entre la courbe de rythme cardiaque foetal et la ligne de base.

Le groupe de Recherche de la Maternité Baudelocque a construit un petit **calculateur digital capable de mesurer cette surface.** Le principe de cet appareil a été décrit par Sureau et al. lors de publications précédentes.

Patientes et méthode

Le signal utilisé pour établir la courbe de rythme cardiaque foetal est l'onde R filtrée de l'électrocardiogramme foetal. La courbe de pression intra-utérine est obtenue à l'aide d'un catheter en plastique introduit dans la cavité utérine et relié à une sonde de pression Statham. Ces deux signaux fondamentaux sont transmis:

a) **vers un cardiotocographe monitor 5** (Roche Bio-electronics),

b) vers un **enregistreur magnétique,**

c) vers le **calculateur de rythme cardiaque.**

Les résultats des calculs sont fournis par un **inscripteur graphique** et par un **inscripteur digital.** A l'aide d'un seuil sur la courbe de pression intra-uterine, nous pouvons obtenir trois types de surface de décélération:

1. **Surface totale (At),**
2. **Surface résiduelle (Ar),**
3. **Surface simultanée (As)** (Fig. 1).

Notre unité de surface est la seconde au carré. Du fait que nous surveillions nos patientes directement en ligne et pendant d'inégales périodes de temps, nous avons ramené les surfaces mesurées à une moyenne horaire et exprimé nos résultats en seconde au carré par heure. Nous avons établi les corrélations entre les résultats obtenus par notre calculateur et le score d'Apgar à la première minute chez 97 nouveau-nés (71 accouchements céphaliques spontanés, 2 sièges, 12 forceps et 12 césariennes).

Résultats

Nous avons trouvé des coefficients de corrélation très significatifs pour chaque type de surface (tab. I)
Nous avons déterminé pour chaque type de surface une valeur limite permettant de prédire les mauvais et les bons scores d'APGAR à la première minute par le calcul des différentes lignes de régression. A partir de celles-ci, nous évaluions sur l'axe des abcisses la valeur de surface correspondant à l'APGAR 7 sur l'axe des ordonnées (fig. 2, 3 et 4). Ces trois valeurs limites furent respectivement 105 secondes carrées par heure pour la surface totale (fig. 5), 70 secondes carrées par beure pour la surface simultanée (fig. 6), et 35 secondes carrées par heure pour la surface résiduelle (fig. 7).
Dans notre groupe, lorsque la surface totale fut inférieure à 105 secondes carrées par heure, le score d'APGAR à la première minute fut égal ou supérieur à 7 dans 88% des cas. Lorsque cette surface fut égale ou supérieure à 105 secondes carrées par heure, le score d'APGAR fut inférieur à 7 dans 94% des cas.

Commentaires

Cette méthode de calcul permet semble-t-il de considérer les **surfaces de ralentissement du rythme cardiaque foetal comme un paramètre plus fidèle de l'état de souffrance du foetus** que la corrélation de temps entre la décélération et la contraction utérine. Nous avons choisi notre unité en fonction de l'intervalle de temps entre deux ondes R.
Par une autre méthode, on pourrait exprimer le rythme cardiaque foetal suivant une échelle de fréquence et mesurer les surfaces en battements manquants.
Du fait de notre petit nombre de patientes, les limites que nous avons établies ne peuvent pas encore être utilisées en pratique.
Les corrélations entre l'état biochimique des foetus et des nouveau-nés et les surfaces de ralentissement seront présentées dans une communication ultérieure.

Mots-clés: Contraction utérine, foetus, rythme cardiaque, score d'APGAR, surface de décélération, surveillance.

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